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REPLICA INSPECTION OF HIGH TEMPERATURE COMPONENTS - LIFE ASSESSMENT, LAKEVIEW UNIT 4

Report No 87-315-K

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ABSTRACT

As part of an overall life assessment program, replica inspection of selected high temperature components in Lakeview, Unit 4, has been carried out by the Metallurgical Research Department. The replica work is intended to identify areas of components that are experiencing high temperature creep degradation which is manifested in the form of creep cavities or microcracking, as well as identifying other damage mechanisms. Creep damage was discovered in only three general areas; the main steam to HP steam chest welds, the IP steam chest, and the IP loop pipes. Re-inspection of these areas is recommended at regular intervals. Other defects in turbine components have been examined and found to be mostly thermal fatigue related and many were associated with manufacturing or repair flaws.

job	file	date	report no.
81-140-520	823.41	March 2, 1988	87-315-K

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EXECUTIVE SUMMARY

REPLICA INSPECTION OF HIGH TEMPERATURE COMPONENTS, LIFE ASSESSMENT LAKEVIEW UNIT 4

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As part of an overall life assessment program, replica inspection of selected high temperature components in Lakeview, Unit 4, has been carried out by the Metallurgical Research Department. The replica work is intended to identify areas of components that are experiencing high temperature creep degradation, which is manifested in the later stages by development of creep cavities or microcracking,as well as identifying other damage mechanisms.

Three major types of components were examined: HP and IP turbines; high energy steam lines; and boiler headers. Over 95 individual areas were selected and examined on the most critical components and locations.

Creep microcracking was discovered in only three general areas; the main steam line to HP steam chest welds, the IP steam chest, and the IP loop pipes. In the HP turbine, creep microcracks were found in the HAZ of the main steam-line chest welds. This damage was the most serious of the three and will require future inspections. Similar microcracking was found in the IP turbine: in the HAZ of weld between the north intercept pipe and the steam chest, and in HAZ of one weld in the loop pipes. Re-inspection of these areas is also recommended at regular intervals. Other defects, mostly in turbine components, have been examined and found to be mainly thermal fatigue related and/or were associated with manufacturing or repair flaws.

Removal of a small sample from the creep damaged area in the IP loop pipe has enabled a detailed investigation that has confirmed the initial findings from the replica and has provided direct evidence of the validity of the replication technique for detection of this form of creep damage.

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**REPLICA INSPECTION OF HIGH TEMPERATURE COMPONENTS
LIFE ASSESSMENT, LAKEVIEW UNIT 4**

INTRODUCTION

As part of the overall life assessment program, replica inspection of selected high temperature components has been carried out by the Metallurgical Research Department. The replica work is intended to identify areas of components that are experiencing high temperature creep degradation which is manifested in the later stages of creep life by the development of creep cavities or microcracking. In the advanced stages of this process macrocracks and rapid failure of the material can result. Prior to the appearance of the creep cavities, the material undergoes other changes in microstructure such as carbide coarsening due to the exposure to high temperatures and the operating stresses. The same replicas can be used to establish estimates of effective operating temperature by quantitative study of the carbide particles extracted with the replica. This work will be reported separately. In this report only the results of the examination of the replicas for creep cavities and microcracks will be presented. It should be noted that the lack of reported cavities does not necessarily imply that the material is totally free of creep damage but only that the process has not reached the stage of cavity development. The replica inspection can also discover and identify other damage mechanisms such as fatigue and thermal shock.

This report will thus summarize the results of the replication work for creep damage and also the results of crack identification work carried out on cracks discovered by other NDE techniques. Three major types of components were examined: HP and IP turbines; high energy steam lines; and boiler headers. The report will be subdivided into these major catergories and will be presented as summaries of the major findings. Details of the individual components and areas are attached as appendices. Each appendix includes descriptions and diagrams of the exact locations examined, as well as microstructural features and hardness results obtained from each area. Selected micrographs from the more seriously damaged areas are included in the bulk of the report. A complete record of typical microstructures from every area has been completed and will be archived, along with the actual replicas, at Research Division for future reference.

RESULTS

A summary of the results from the areas that contained any significant damage is provided by Table 1. The microstructures of the components not included in the table are considered as satisfactory, i.e. containing features typically expected for the material after exposure to elevated temperatures for approx 100,000 hours. Generally the components were in a satisfactory condition with no creep damage being apparent at this time. Only four instances of creep damage were found and three of these were either associated with or influenced by previous manufacturing defects. However several instances of major cracking caused by other mechanisms were investigated.

1.0 HP Turbine Components

Two areas of creep damage were found in the HP turbine components: main steam line to chest welds and one weld in the upper loop pipes. The most serious of these was the main steam welds. Three areas were examined; two on the north pipe and one on the south pipe and all contained the same degree of damage. Examples are shown in Figure 1. The microcracks were located in the coarse grained HAZ of the main steam side of the weld only and were oriented parallel to the pipe axis and tranverse to the weld fusion line. They were thus located exclusively in the P11, 1 1/4 Cr, 1/2 Mo material The cracks were intermittent and were not generally interconnected but appeared to occur throughout the circumference although the entire circumference was not examined. According to the European classification this damage would be categorized as type B-C, i.e. representing no immediate threat to the integrity of the component but indicating that the material is entering the tertiary stage of creep. As such these welds should be re-examined at some future date, say after another 10,000 hours.

In the other area containing creep damage, the loop pipe weld, the defect was located in a weld between two 1/2 Cr 1/2 Mo V sections and was an isolated crack less than 1 cm in length (Figure 2). Evidence of intergranular creep micro-voids were found around the crack indicating that the crack was growing by creep mechanisms. However considering its location and its singularity, the main crack was probably produced during the initial welding and is extending by creep processes. It does not require any further action at this time but the weld should be monitored on a regular basis.

Cracks were discovered in both the outer and inner HP cylinders and two of these were examined by replicas. Both appeared to be thermal fatigue cracks. The outer cylinder cracking was extensive but was associated with a previous repair weld that had not been adequately stress relieved (Figure 3). The characteristics of the cracking were indicative of hydrogen cracking that had occurred during or immediately after the repair weld. There was some evidence that these initial cracks were propagating by fatigue mechanisms. The inner cylinder cracks were not associated with any manufacturing flaw or other defect but had the characteristics of thermal fatigue (Figure 4). Some degradation of the microstructure and mechanical properties was apparent in this area. Removal or repair of these defects should be considered if not already done.

2.0 IP Turbine Components

Similar to the HP components, damage to the IP was of two types; creep damage and thermal fatigue or thermal shock.

The creep damage was minor and associated with manufacturing defects and associated local stress concentrations. Two areas were found: the weld between the north intercept pipe and the north steam chest and one weld on the upper loop pipes. The material in all cases was 1/2 Cr 1/2 Mo V. The damage in the north intercept pipe was in the form of one macrocrack and numerous microcracks and cavities in the HAZ but was confined to only a short area of the circumference of the weld (Figure 5). Welds on similar sites on the chests and manifolds contained no signs of advanced creep. An apparent repair weld was present just beside the main weld in the area of the damage. It is probable that residual or system stresses associated with this weld are primarily responsible for the creep damage in this particular location.

The area in the loop pipe weld was examined in some detail by replication and by removal of a small boat sample from the pipe. This provided an opportunity to compare the results from the replicas with the actual material. The appearance of the defective area as it was discovered on the uncoated field replica is shown in Figure 6a. Microcracks and oriented grain boundary cavities are found in the HAZ lying roughly parallel to the weld fusion line. In the same area and sometimes associated with the microcracks were large manganese sulphide inclusions (white patches in Fig 6a). Better resolution of the microstructural aspects of the cracking can be seen in the actual sample (Fig 6b). This view shows that the microcracks are in fact intergranular. Comparisons of the replicated features with their actual appearance on the removed piece are presented in Figure 7. Both sets of micrographs show the association of the more advanced cracks with the inclusions as well as the oriented microcavities. The fidelity of the replication technique in revealing this type of damage is clearly illustrated by these micrographs. The removed sample was cross sectioned transverse to the cracking to determine the depth of the damage. The results showed that the defective area was superficial. Randomly dispersed grain boundary cavities were found to a depth of 2.5 mm. An example is shown in Figure 8a. An example of oriented microcavities associated with carbide particles is illustrated in Figure 8b.

Although both of these defects were associated initially with manufacturing flaws the results do show that the creep processes must be reasonably well developed in the loop pipes and detectable damage is only appearing in the more highly stressed areas around existing flaws. Monitoring of these areas by repeated replication at regular intervals is advisable.

The other major defects which were examined in the IP components were mostly thermal fatigue cracks. Three major cracks were analyzed on the inner surfaces of the outer cylinder. The one on the lower cylinder in the nozzle area was thought to be an original casting defect but the larger cracks in the lower cylinder were thermal fatigue cracks with some evidence that relatively recent thermal shocks were also factors in the crack propagation (Figure 9). Thermal fatigue cracks were also present in the areas examined on the outer surfaces of the inner cylinder. These cracks were somewhat unique in that

they were associated with some microstructural analomies produced during the casting process. An example is shown in Figure 10. Non metallic inclusion particles have acted as nucleation sites for the initial ferrite grains that formed from the austenite as the casting cooled. The result was areas of large grained ferrite surrounding the inclusion stringers. The fatigue cracks have preferentially followed the weaker large grain ferrite regions.

Two defects were also examined in the IP rotor shaft. Cracks at the hot end appeared to be fatigue but were superficial and were removed by light grinding (Figure 11). The cracks in the stage 4-5 region were more serious and had likely been produced by a previous heat straightening operation. Rapid cooling had produced an untempered microstructure and quench cracks (Figure 12).

3.0 Boiler Components-Headers

The three headers that were examined,the primary superheater outlet header, the secondary superheater outlet header and the reheat outlet header contained no damage from creep processes. Some slight but not unexpected degeneration of the pearlite phase in the primary superheater outlet header was found. Apart from that the only defect examined was a fatigue crack in one of the nipple welds in the secondary superheater outlet header.

4.0 High Energy Steam Lines

No advanced damage of any kind was found in the areas examined in the main steam and reheat lines except for the creep cracks found in the terminal welds on the main steam lines which have been described above under HP turbine components.

CONCLUSIONS

1. Replica inspection of selected areas on high temperature components has discovered creep cavities and microcracks in only three general areas; the main steam to HP steam chest welds, the IP steam chest, and the IP loop pipes. The former was in 1 1/4 Cr 1/2 Mo V and the latter two in 1/2 Cr 1/2 Mo V material. Re-inspection of these areas is recommended on regular intervals.

2. Other defects in the turbine components have been examined and found to be mostly thermal fatigue related and many were associated with manufacturing or repair flaws.

3. Removal of a small sample from one of the creep damaged areas has enabled a detailed investigation that has confirmed the initial findings from the replica. This exercise has provided direct evidence of the validity of the replication technique for detection of this form of early creep damage.

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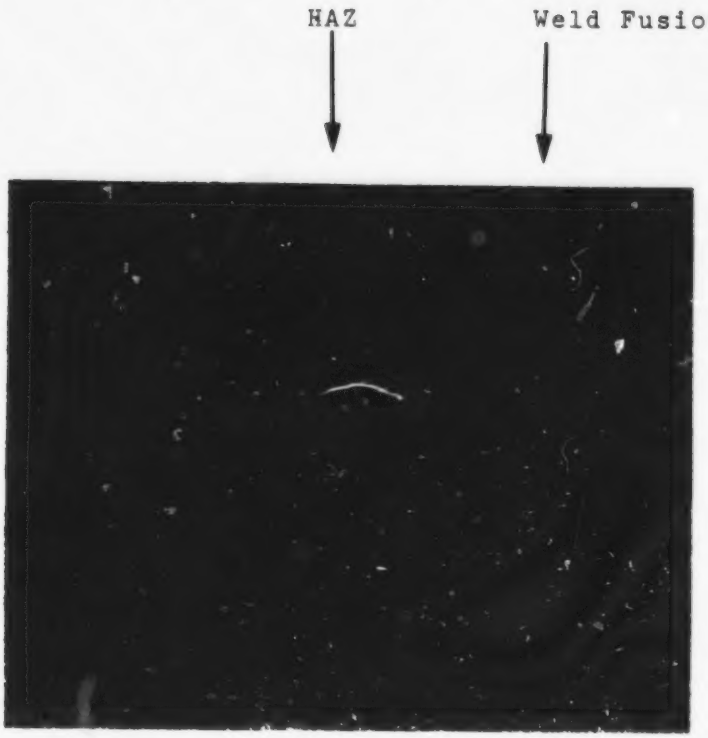
TABLE 1

AREAS CONTAINING SIGNIFICANT DAMAGE

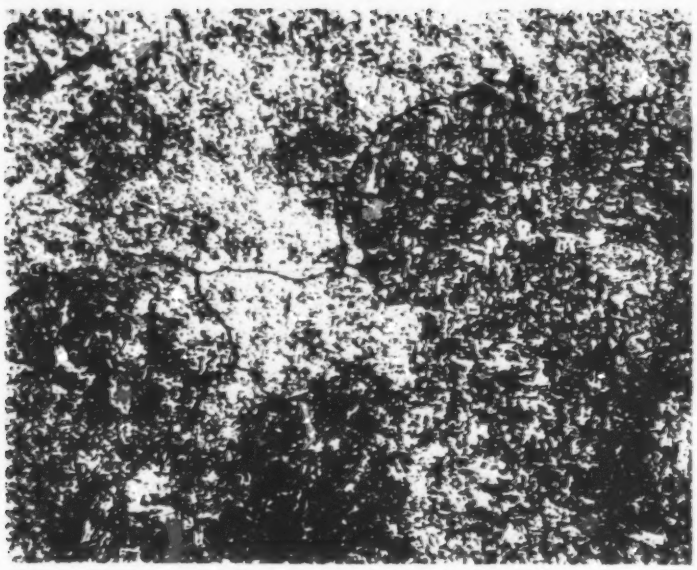
COMPONENT	AREA	MECHANISM
HP Turbine - Steam Chests	Main steam to chest welds	Creep cracking
HP Turbine - Loop Pipes	South pipe weld	Weld defect plus creep
HP Turbine -Outer cylinder -Bottom half	Inner surface Between nozzles	Hydrogen crack from repair weld
HP Turbine -Inner cylinder -Top half	Hot end nozzles	Thermal fatigue
IP Turbine - Steam Chests	North intercept pipe to chest weld	Creep cracking - weld repair
IP Turbine - Loop pipes	South pipe weld HAZ	Creep cracking-inclusions
IP Turbine -Outer cylinder	Lower half, nozzle	Casting defect
IP Turbine -Outer cylinder	Upper half, nozzles	Thermal shock
IP Turbine -Inner cylinder	Upper half, outer surface	Thermal fatigue plus casting defect
IP Rotor Shaft	Hot end, Gland	Fatigue
IP Rotor Shaft	Stage 4-5	Quench cracking
Secondary superheater - Outlet header	Nipple weld, east end	Fatigue



X 200

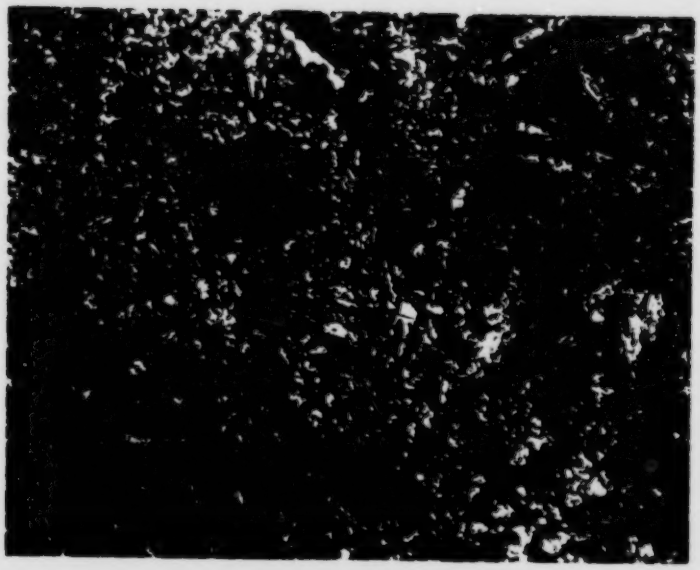
X 200

FIGURE 1 - CREEP DAMAGE IN MAIN STEAM LINE TO HP STEAM CHEST WELDS, REPLICA #24



X 100

FIGURE 2 - INTERGRANULAR CRACK IN WELD METAL, HP LOOP PIPE, REPLICA #12



a) X 200

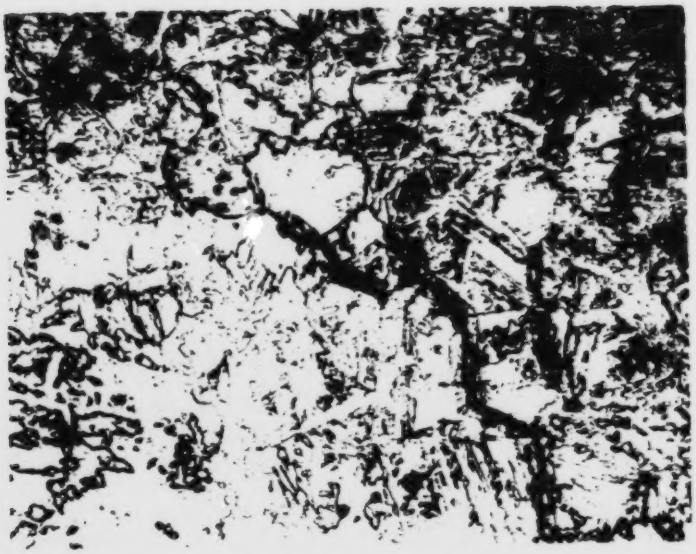
b) X 200

FIGURE 3 - CRACKING AND MICROSTRUCTURES IN HP OUTER CYLINDER, REPLICA #55

a) X 50

b) X 100

FIGURE 4 - THERMAL FATIGUE CRACKS IN HP INNER CYLINDER, REPLICA #40



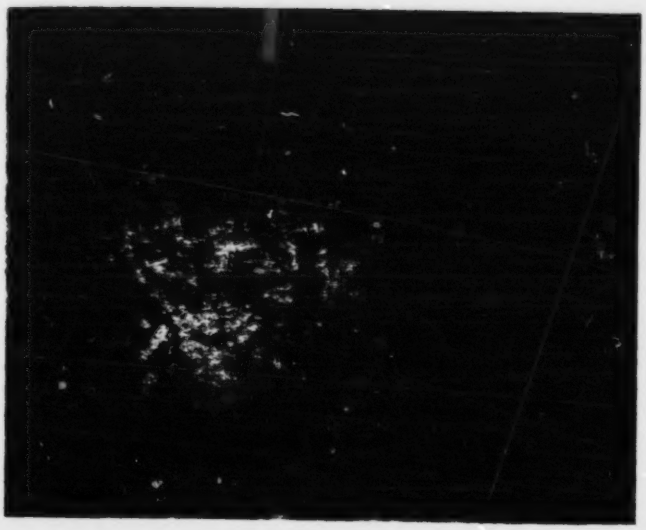
X 200

X 400

FIGURE 5 - CREEP CRACKING IN STEAM CHEST TO NORTH INTERCEPT PIPE WELD, REPLICA #52

a) Uncoated Replica, X 400 b) Actual Sample, X 400

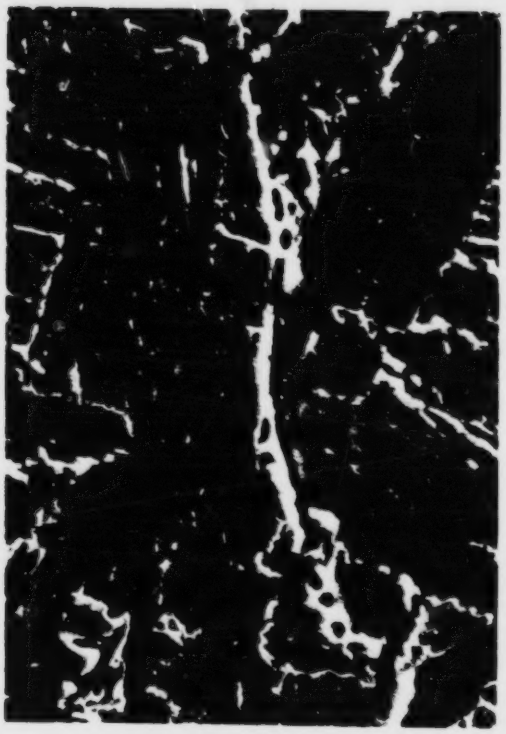
FIGURE 6 - CREEP DAMAGE IN IP LOOP PIPE WELD, SAMPLE REMOVED FROM AREA #5



a) Coated Replica, Optical Microscope, X 600

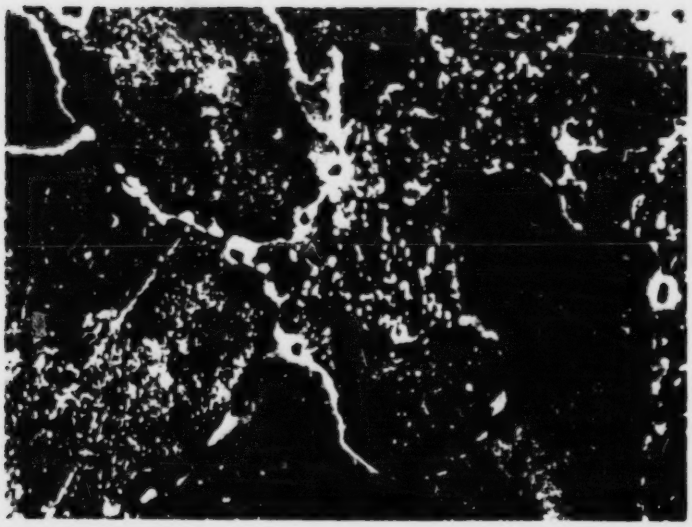
b) Actual Sample, SEM, X 2000

c) Replica, Optical Microscope, X 600

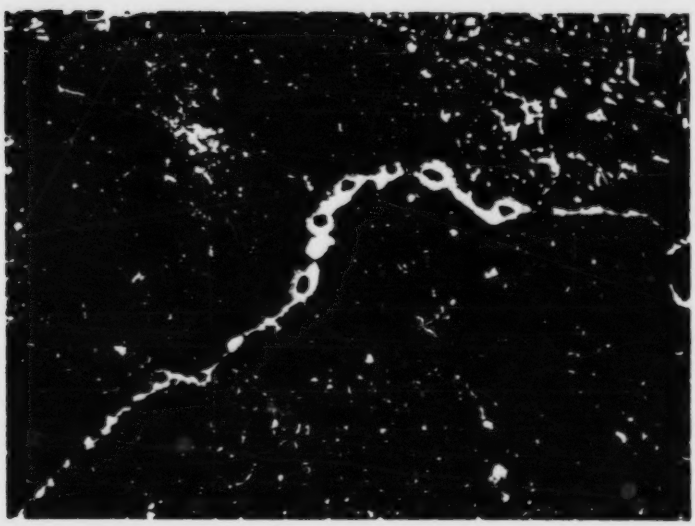


d) Actual Sample, SEM, X 2000

FIGURE 7 - DETAILS OF CRACKING, LOOP PIPE, AREA #5



a) Random Cavities, X 2000



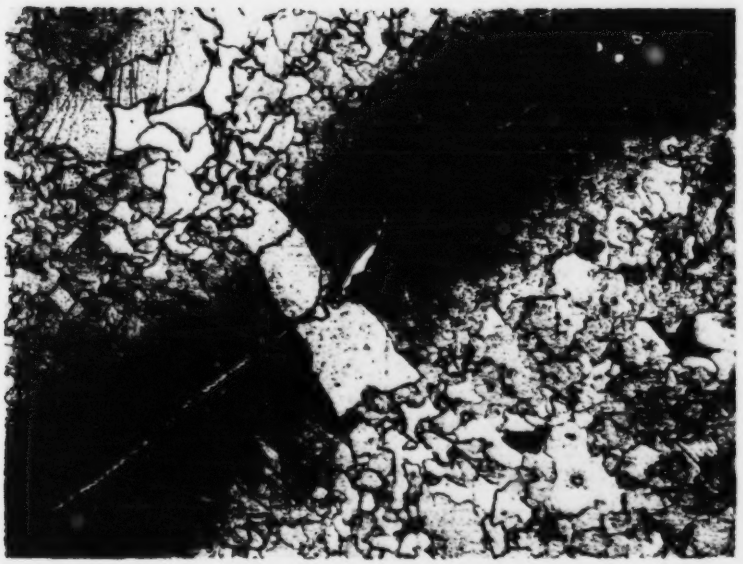
b) Oriented Cavities at Grain Boundary
Carbides, X 2000

FIGURE 8 - CREEP CAVITIES, ON CROSS-SECTION OF SAMPLE REMOVED FROM AREA 5

a) X 50

b) X 100

FIGURE 9 - THERMAL SHOCK CRACKS IN IP OUTER CYLINDER, REPLICA #81



a) Crack Tip, X 100

b) Inclusions & Coarse Grained Ferrite, X 200

FIGURE 10 - CRACKING IN IP INNER CYLINDER, REPLICA #54

a) X 50

b) X 200

FIGURE 11 - CIRCUMFERENTIAL FATIGUE CRACKS IN IP, ROTOR SHAFT, REPLICA #79

FIGURE 12 - CRACKS IN IP ROTOR, STAGE 4-5, REPLICA #60, X 100

APPENDIX A - HP TURBINE COMPONENTS

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: HP Turbine-Steam Chests and Related Piping

MATERIAL: Chest-1/2Cr 1/2Mo V (GEC30/411)casting
Cross under Pipe-1/2Cr 1/2Mo V
Main Steam Line-A335 Gr P11,1 1/4Cr 1/2Mo

AREA DESCRIPTION: 8 areas: #23,#25 high stress areas on casting
#26,27,28 welds on connecting pipes
#24,36,49 welds between main steam line and chest
#83,inside steam bowl,west bowl,south side

MICROSTRUCTURE AND HARDNESS

AREA	23	25	83	26		27	28
STRUCTURE	ferrite carbide			same			
HARDNESS (HV)	151	153	233	BM	140(chest)	180(y piece)	137(y piece)
				HAZ	na	250	172
				WM	132	187	169
				HAZ	161	196	157
				BM	125(pipe)	164(pipe)	117(chest)

DAMAGE ASSESSMENT: Creep damage found in main steam line to chest weld in the coarse grained HAZ(#24,36,49). Microcracks and isolated intergranular cavities were present only in the main steam side of the HAZ in both the north and south pipes. Cracks were oriented parallel to the pipe axis and transverse to the weld fusion line,were found around the entire circumference (of the area examined), but were not interconnected.

All other areas contained no damage.

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: HP Turbine-Steam Chests and Related Piping cont'd

MATERIAL: *

AREA DESCRIPTION: *

MICROSTRUCTURE AND HARDNESS

AREA		24	36	49
STRUCTURE		Ferrite carbide	same	same
HARDNESS (HV)	BM	na	145	143(chest)
	HAZ		na	na
	WM		129	144
	HAZ		133	131
	BM		112	108(pipe)

DAMAGE ASSESSMENT: *

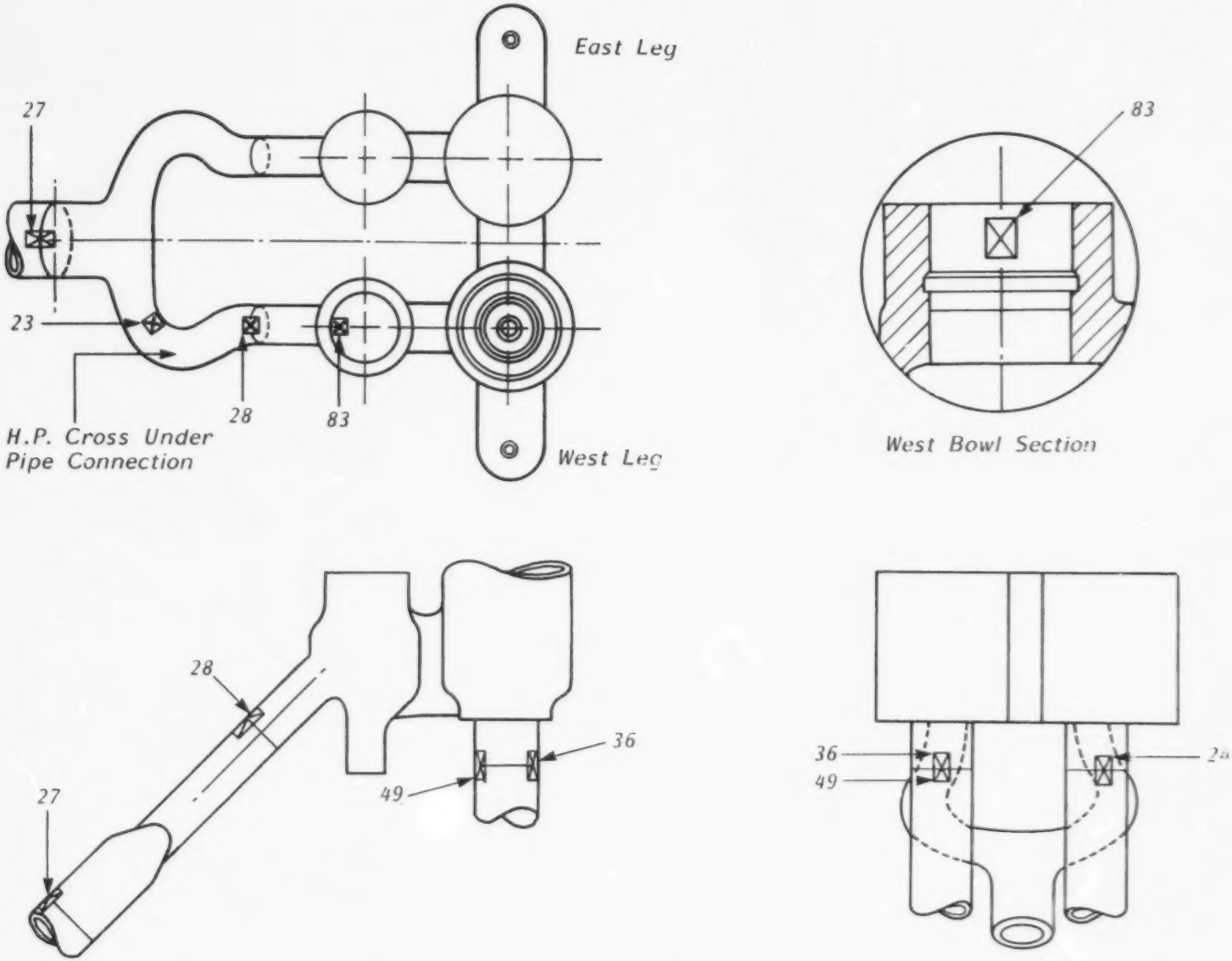


FIGURE A-1

REPLICA LOCATIONS - H.P. TURBINE CIESV GV STEAM CHEST - SOUTH

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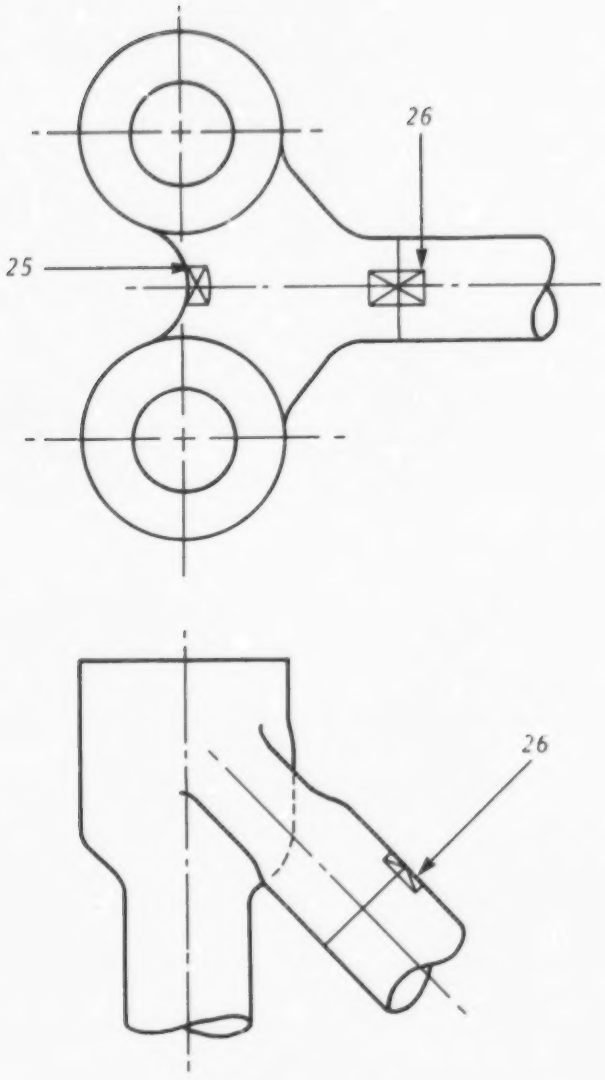


FIGURE A-2

REPLICA LOCATIONS - H.P. TURBINE GOVERNOR VALVE
STEAM CHEST - NORTH

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: HP Turbine-Loop Pipes

MATERIAL: 1/2Cr 1/2Mo 1/4V

AREA DESCRIPTION: 7 areas; welds,#7,10,11,12
bailey joints,#6,9
bends,#8

MICROSTRUCTURE AND HARDNESS

AREA	6	7	8	9
STRUCTURE	Ferrite, carbide	same	ferrite, twinning	same
HARDNESS (HV)	215	BM 138(L,casting) HAZ 163 WM 249 HAZ 190 BM 160(R,pipe)	131	218

DAMAGE ASSESSMENT: No general damage found. A small crack (10mm) in the weld metal on the south pipe (area #12) appears to be growing by a creep mechanism. Intergranular crack path and some grain boundary creep cavities were apparent. However the damage is localized and likely originates with a pre-existing weld defect.

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: HP Turbine-Loop Pipes(cont'd)

MATERIAL: *

AREA DESCRIPTION: *

MICROSTRUCTURE AND HARDNESS

AREA	10	11	12
STRUCTURE	Ferrite-carbide	same	same crack in weld metal
HARDNESS (HV)	BM 212(L,casting)	228(R,casting)	na
	HAZ 245	218	na
	WM 249	198	na
	HAZ 186	225	na
	BM 162(R,pipe)	167(L,pipe)	na

DAMAGE ASSESSMENT:

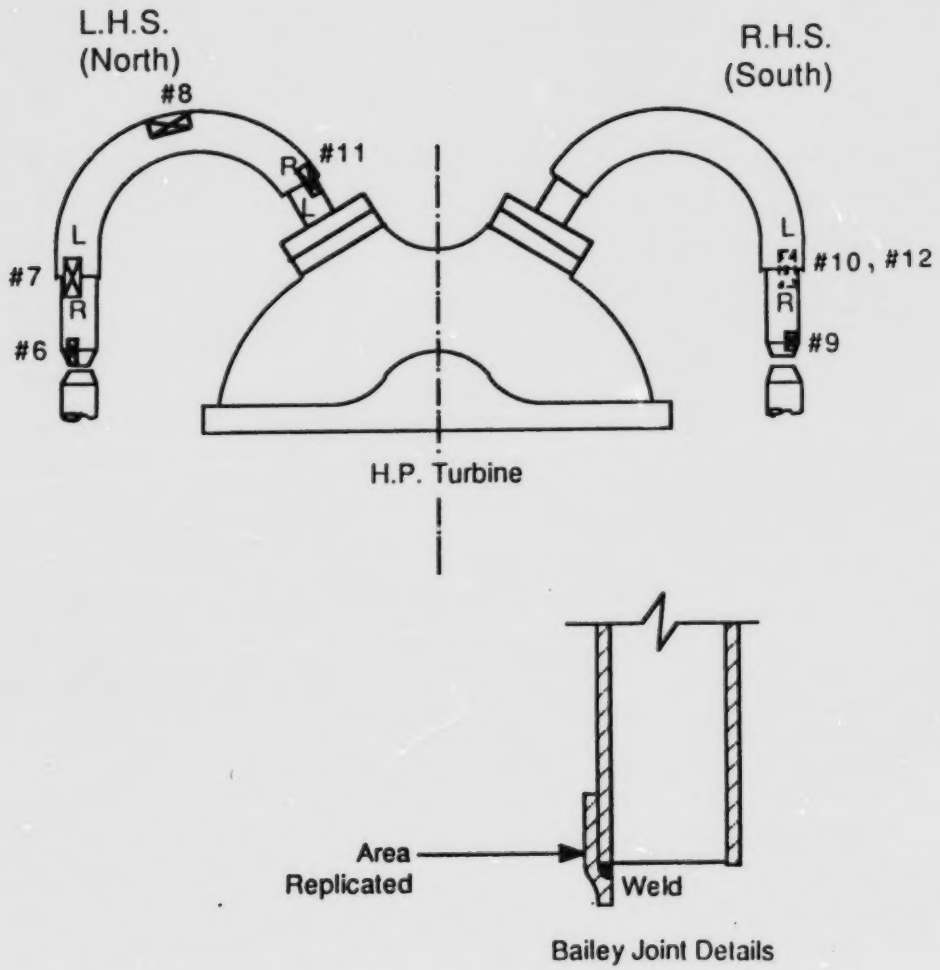


FIGURE A-3
REPLICA LOCATIONS - HP LOOP PIPES

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: HP Turbine-Outer Cylinder,Bottom Half

MATERIAL: 1/2Mo casting

AREA DESCRIPTION: 1 area: #55,on inner surface at outlet end between the outlet nozzles, replica of major 75mm crack.

MICROSTRUCTURE AND HARDNESS

AREA 55

STRUCTURE Ferrite-carbide
Repair weld-martensite in HAZ

HARDNESS (HV) BM 236
HAZ 211-361
WM 265

DAMAGE ASSESSMENT: Cracking was associated with a previous repair weld which appeared not to have been stress relieved. The crack originated in the HAZ of the weld which contained hard regions up to 361 HV. Crack features indicate that the original crack was caused by hydrogen cracking mechanism but may have been propagating by fatigue in service.

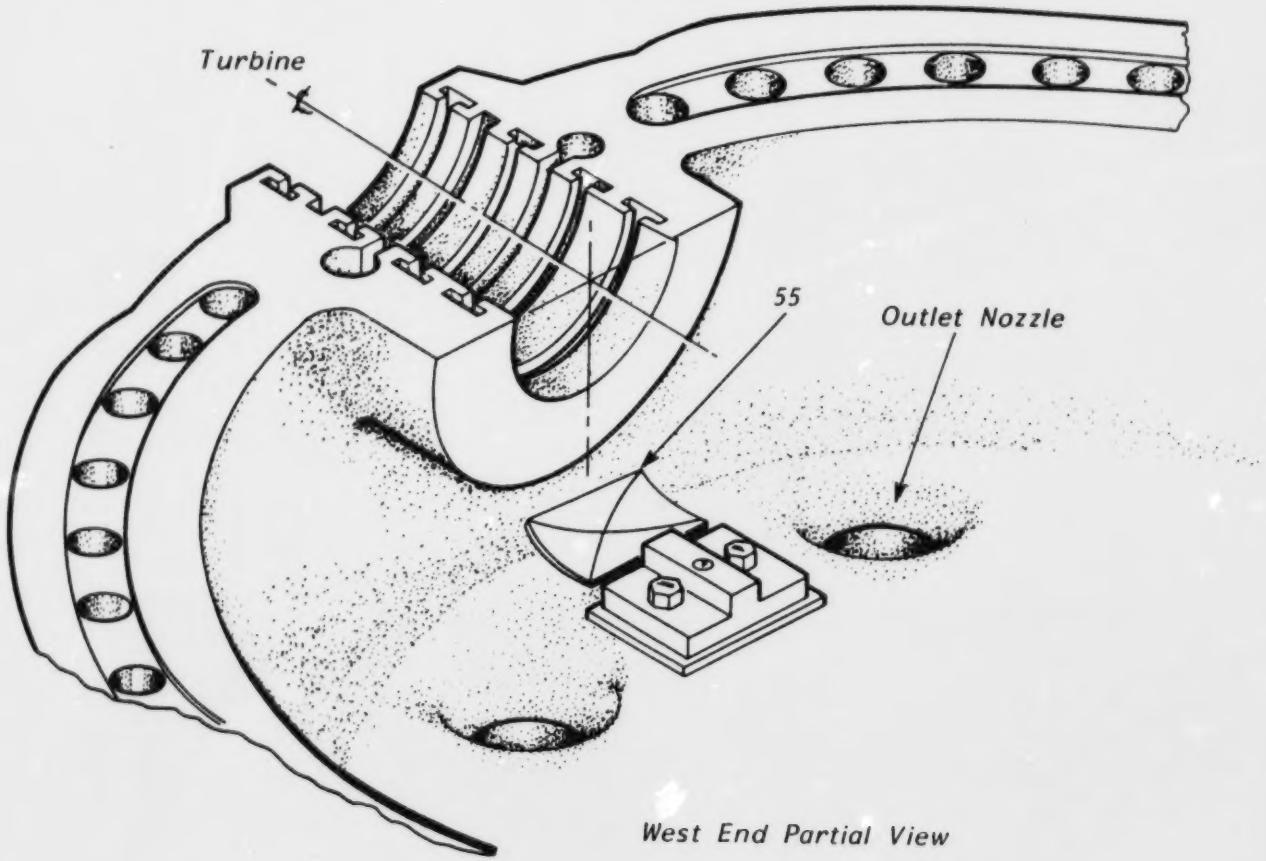


FIGURE A-4

REPLICA LOCATIONS - H.P. TURBINE
OUTER CYLINDER, BOTTOM HALF

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: HP Inner Cylinder (Top Half)

MATERIAL: 1/2 Cr 1/2 Mo V (casting)

AREA DESCRIPTION: 2 areas on top half;
#40 hot end-between nozzle inlets next to small hole with visible cracks.
#39 cold end-on transverse plane at end of cylinder.

MICROSTRUCTURE AND HARDNESS

AREA	39	40
STRUCTURE	ferrite with some pearlite twinning, cracks	ferrite larger grains
HARDNESS (HV)	162	123

DAMAGE ASSESSMENT: Hot end cracking is thermal fatigue. No creep damage was noted. The twinning is not deterimental. Some thermal softening at the hot end is indicated by the decrease in hardness from cold to hot ends.

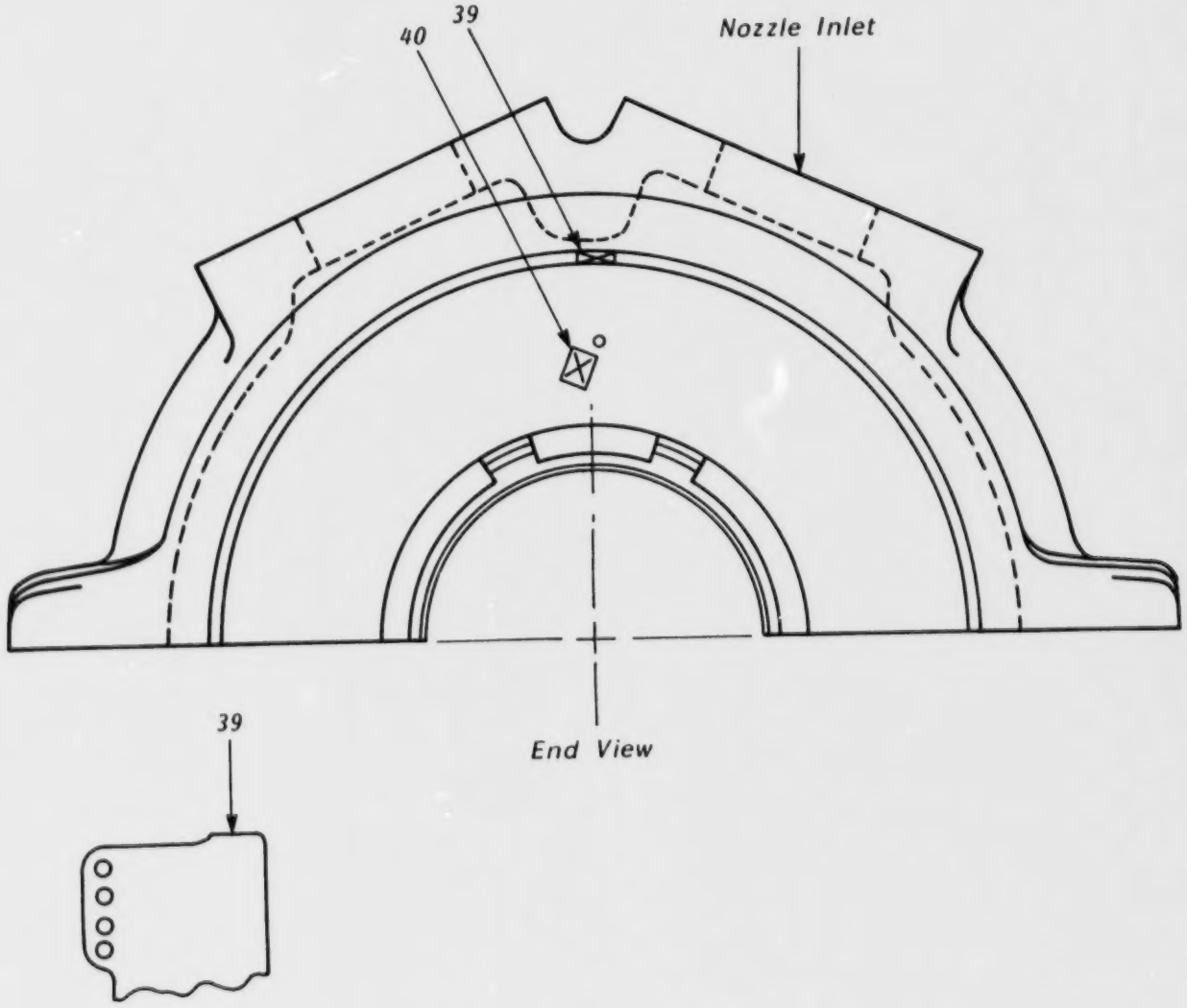


FIGURE A-5
REPLICA LOCATIONS - H.P. INNER CYLINDER (TOP HALF)

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT:	HP Nozzle Block #2
MATERIAL:	1/2CR 1/2Mo V (Casting)
AREA DESCRIPTION:	One area #35 on outer surface in radius of inlet nozzle

MICROSTRUCTURE AND HARDNESS

AREA	35
STRUCTURE	Ferrite small amount of pearlite
HARDNESS (HV)	192

DAMAGE ASSESSMENT: no damage

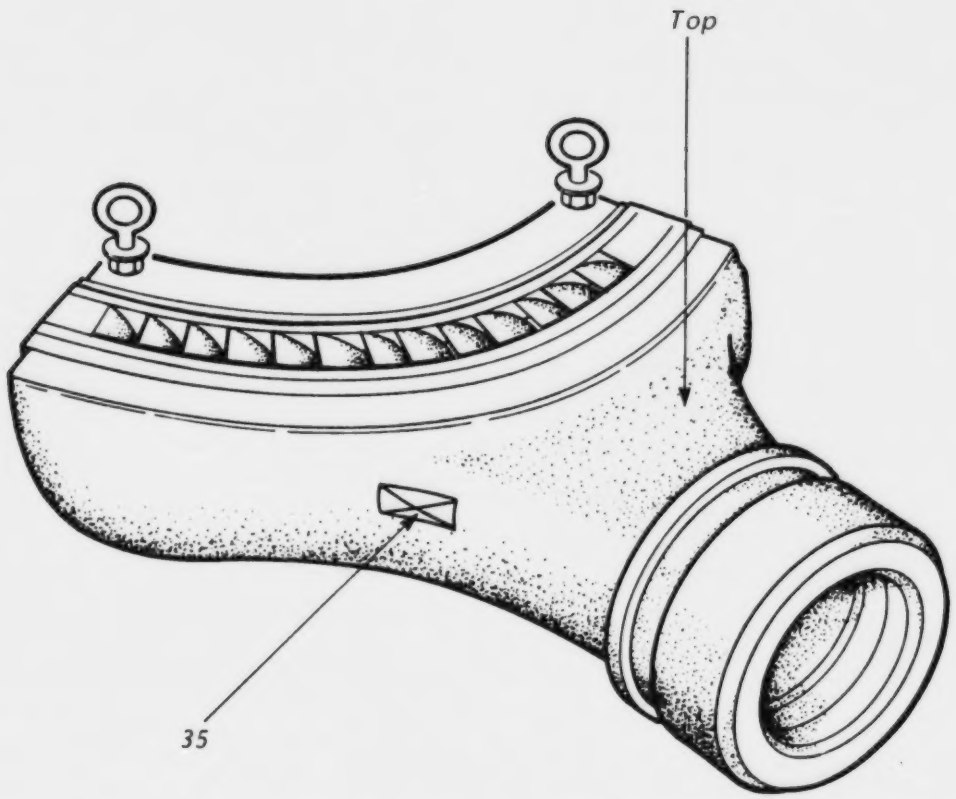


FIGURE A-6
REPLICA LOCATIONS - H.P. NOZZLE BLOCK #2

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: HP Turbine-Rotor Shaft

MATERIAL: 1/4Cr Mo 1/4V, forging

AREA DESCRIPTION: 6 areas on outboard faces of the end discs:
#29, cold end, stage 8 in radius
#30 to #34, hot end, stage 1 in radius
blade attachments and balance holes

MICROSTRUCTURE AND HARDNESS

AREA	29	30	31	32	33	34
STRUCTURE	Ferrite-carbide	same	same	same	same	same
HARDNESS (HV)	180	191	203	220	207	223

DAMAGE ASSESSMENT: No damage detected

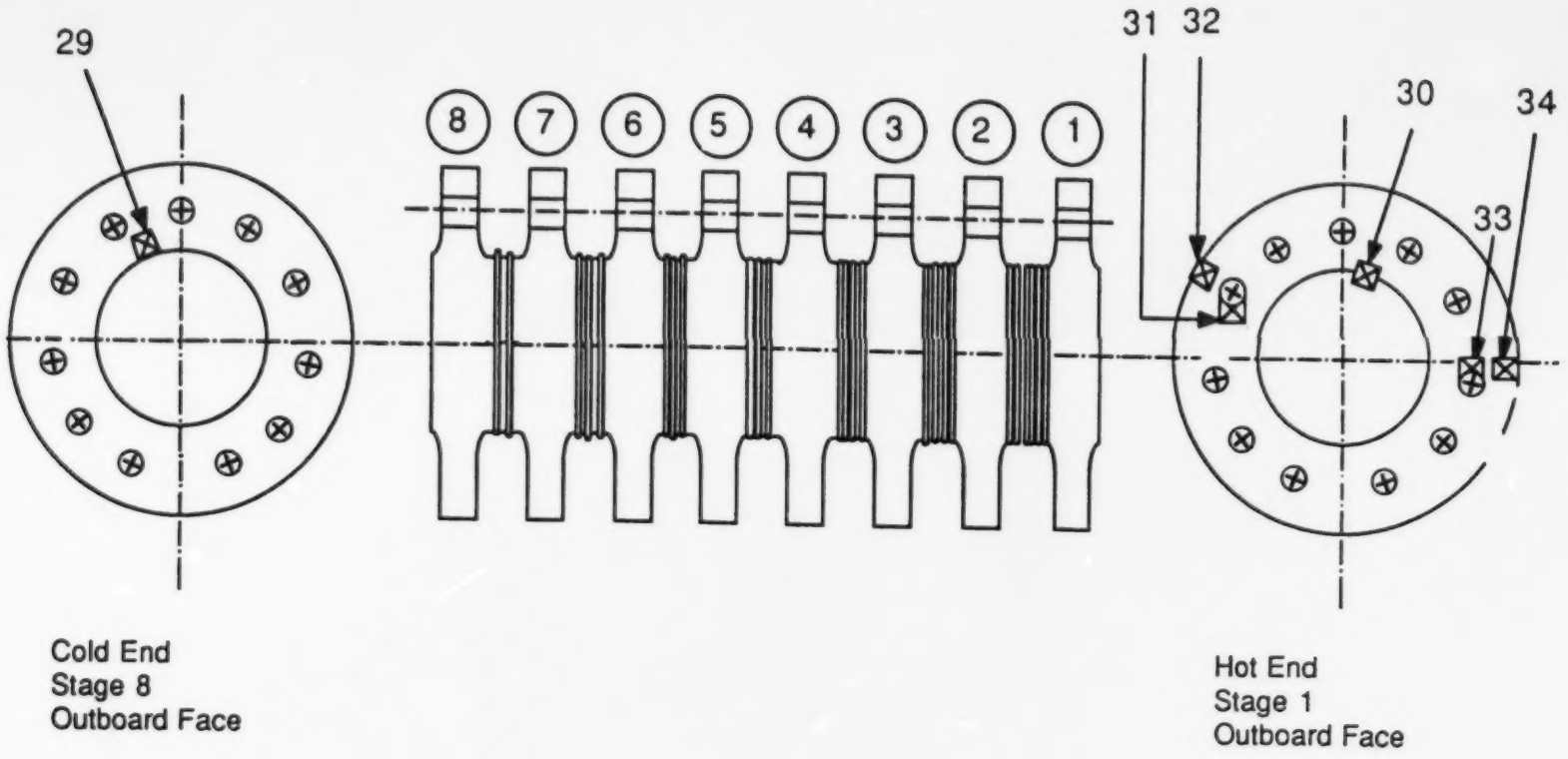


FIGURE A 7
REPLICA LOCATIONS - H.P. TURBINE ROTOR SHAFT

176068 RD
KNARF 2 DISK
87-315

APPENDIX B - IP TURBINE COMPONENTS

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: IP Turbine-Reheat(Intercept) Steam Chests,Manifold and Inlet Pipes

MATERIAL: 1/2Cr 1/2Mo V castings and pipe

AREA DESCRIPTION: 7 areas: #47,48 welds between reheat pipe and manifold
#50, steam chest body
#51,98B, welds between manifold and intercept pipes
#52,98,98A, weld between north intecept pipe and chest
#82, inside west bowl,south side of chest

MICROSTRUCTURE AND HARDNESS

AREA	47	48	50	51	52,98	82	98A,98B
STRUCTURE	Ferrite carbide	same	same, large grains	same	same, large grains, crack	same	
HARDNESS (HV)	BM 130(manifold)	122	120	105	118	132	
	HAZ na	153		156	174		
	WM 179	190		140	186		
	HAZ 143	181		163	214		
	BM 127(pipe)	134		118(pipe)	142(pipe)		

DAMAGE ASSESSMENT: Creep damage was found in the steam chest to north intercept pipe weld, area #52, in the coarse grained HAZ of the pipe side of the weld. One macrocrack 5 mm in length was found oriented circumferentially to the pipe, parallel to the weld fusion line. Intergranular microcracks and cavities were present in the same general area for approximately 25 mm of the weld. A repair weld area was present on the pipe about 5mm from the main weld Residual stresses from this weld, along with system stresses may have been affecting the area containing the cracks. Repeat replicas in the same and adjacent areas, #98,98A, confirmed the findings but also found that the damage was confined to the one small area of the weld. Similar welds, (98B,51) contained no damage. Unfortunately the identical weld on the south intercept was not accessible.

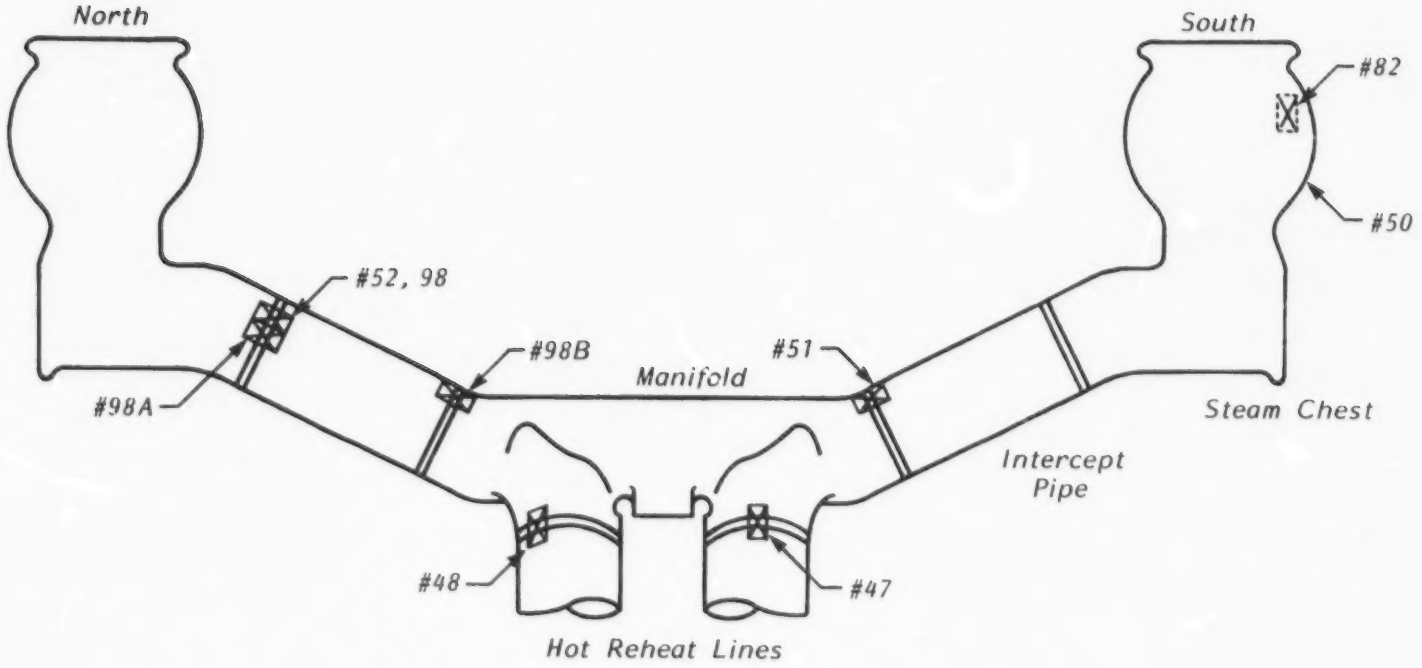


FIGURE B-1

REPLICA LOCATIONS - IP TURBINE
INTERCEPT STEAM MANIFOLD AND INLET PIPES

176089 RD
87-315

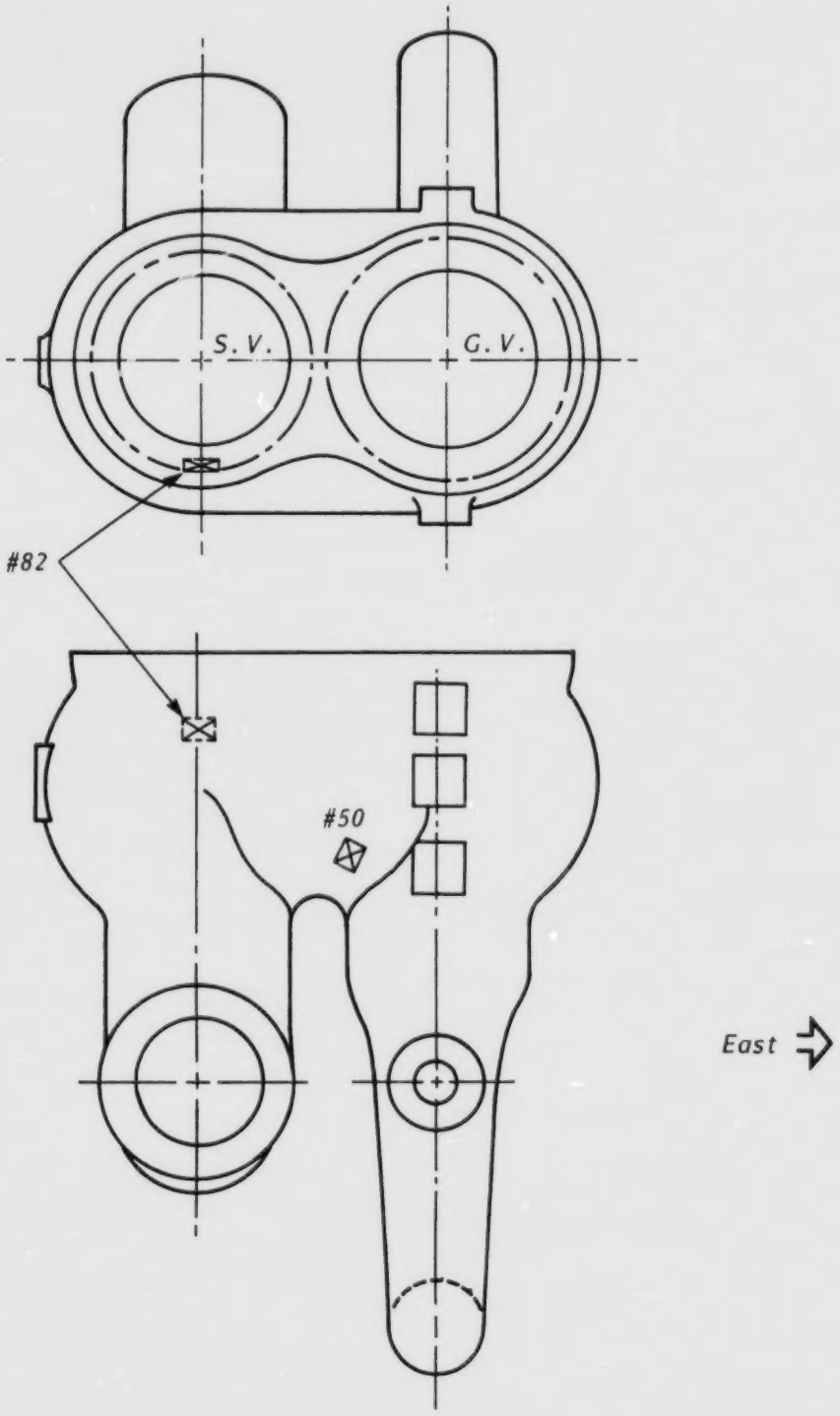


FIGURE B-2

REPLICA LOCATIONS - I.P. TURBINE
SOUTH STEAM CHEST - VIEW FROM SOUTH

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: IP Turbine-Loop Pipes

MATERIAL: 1/2Cr 1/2Mo 1/4V

AREA DESCRIPTION: 6 areas; #2,4,5,13,welds
#1,3,bailey joints
1 sample piece removed from area #5

MICROSTRUCTURE AND HARDNESS

AREA	1	2	3	4
STRUCTURE	Ferrite-carbide	same	same	same
HARDNESS (HV)	191	BM 223(B,casting) HAZ 246 WM 241 HAZ 190 BM 156(T,pipe)	188	255(B,casting) 254 230 201 164(T,pipe)

DAMAGE ASSESSMENT: No general damage found. One area of creep cracking found in the weld of area #5(13). This cracking was associated with massive manganese sulphide inclusions which were generally found throughout the casting. Cracking was confined to the one small area in the weld and was not found in any of the other welds. Sample removal confirmed the creep cracking and associated cavitation and found that the crack depth was superficial (less than mm). The combination of the HAZ microstructure and the stress concentrations due to the inclusions has initiated the cracking.

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: IP Turbine-Loop Pipe(cont'd)

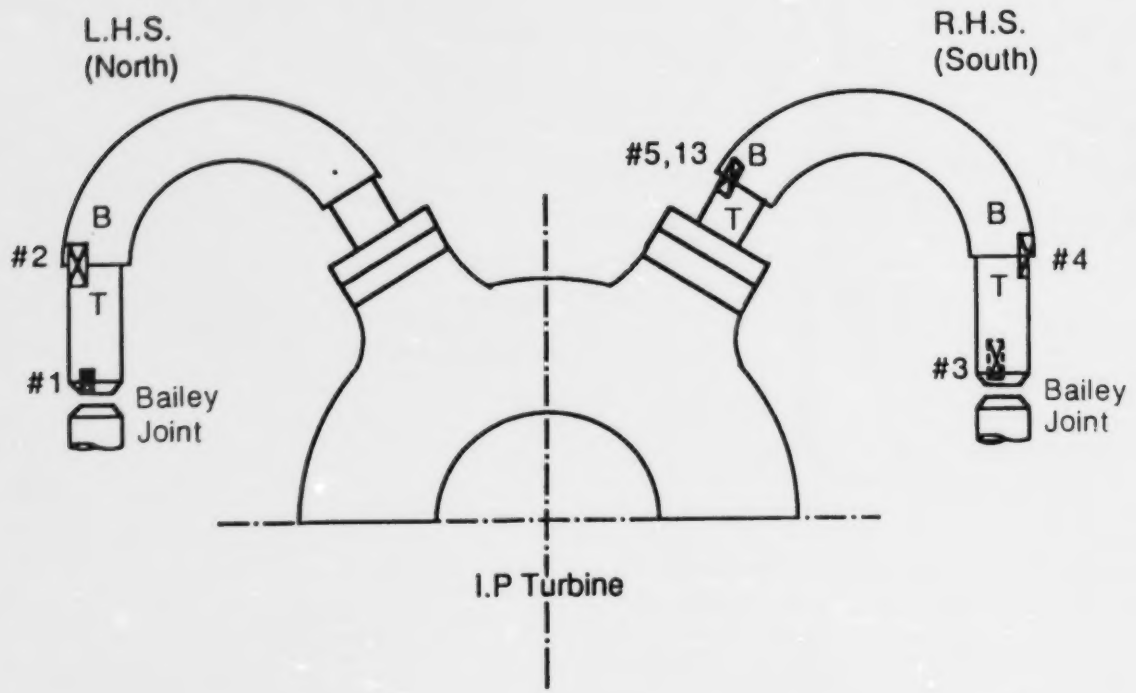
MATERIAL: *

AREA DESCRIPTION: *

MICROSTRUCTURE AND HARDNESS

AREA	5,13(redo of 5)
STRUCTURE	Ferrite- carbide cracks at large inclusions
HARDNESS (HV)	BM 205(B,casting) HAZ 205 WM 177 HAZ 170 BM 119(T,pipe)

DAMAGE ASSESSMENT: *



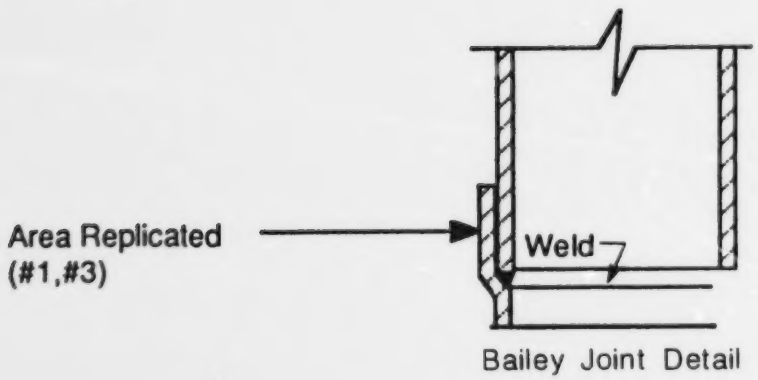


FIGURE B-3
REPLICA LOCATIONS - IP LOOP PIPES

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: IP Turbine-Outer Cylinders

MATERIAL: 1/2Mo casting

AREA DESCRIPTION: 3 areas: #53 lower cylinder cracks on inner nozzle area
#81 upper cylinder, long crack on inner surface
#81A upper cylinder, short crack on inner surface

MICROSTRUCTURE AND HARDNESS

AREA	53	81	81A
STRUCTURE	Ferrite-pearlite, upper bainite	Ferrite-bainite	Ferrite-pearlite
HARDNESS (HV)	na	na	na

DAMAGE ASSESSMENT: The short crack in the nozzle area of lower cylinder, #53, appeared to be an original casting defect. It was located in a region where the microstructure changed from predominately ferrite-pearlite to ferrite with upper bainite which reflects different quenching rates and/or alloy segregation. It was also located on the intersection of the nozzle with the inner bore surface. Both of these factors could conceivably produce cracking.

The major cracks on the upper half of the cylinder (#81,81A) were transgranular, branched, segmented and mostly oxide filled. Minor side branches had the straight transgranular appearance usually found in rapid brittle crack propagation. These minor branches were not oxidized and were commonly found close to the ends of the major cracks. These features suggest that the cracks have propagated recently. All of the features are indicative of a thermal shock mechanism.

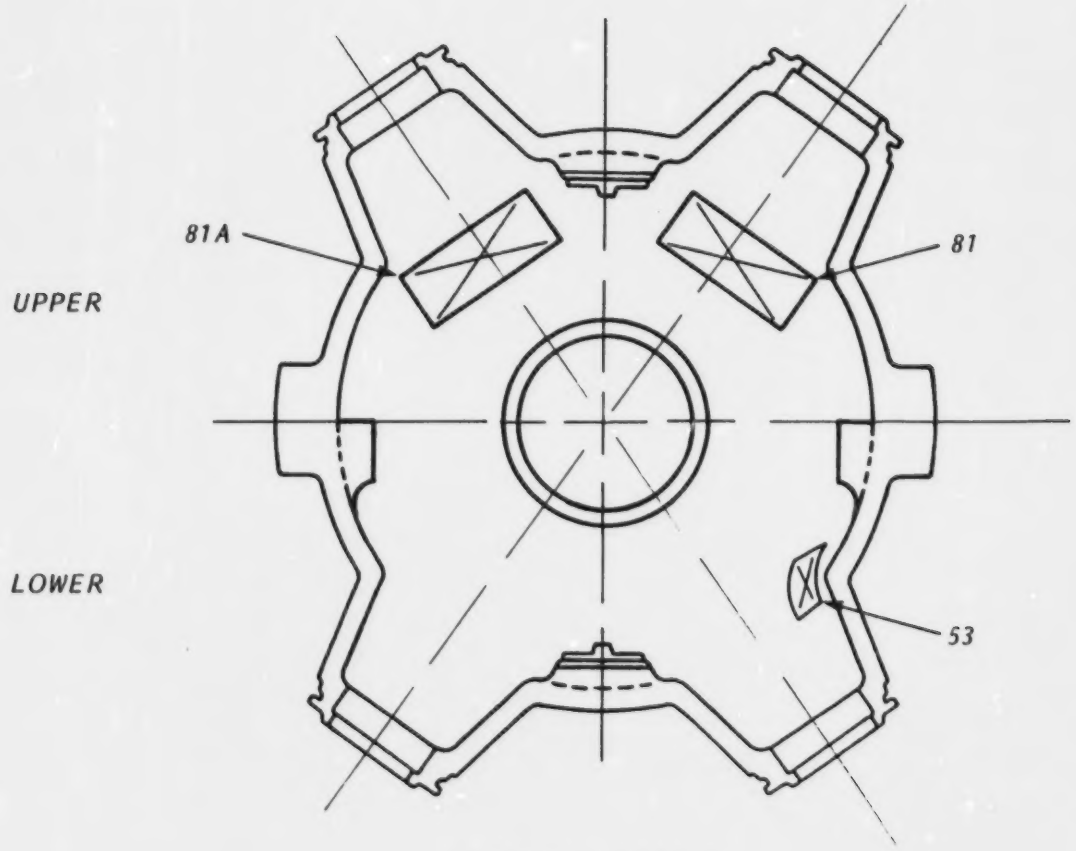


FIGURE B-4
REPLICA LOCATIONS - I.P. TURBINE OUTER CYLINDER

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: IP Turbine-Inner Cylinder, top half

MATERIAL: 1/2Cr 1/2Mo 1/4V casting

AREA DESCRIPTION: 3 areas: #37, cold end face
#38, hot end, steam inlet opposite first set of blades
#54, outer surface, around bolt holes LHS, next to bolt hole 4-5 from cold end

MICROSTRUCTURE AND HARDNESS

AREA	37	38	54
STRUCTURE	ferrite-few carbides	same	ferrite, some twinning, cracks
HARDNESS (HV)	142	168	145

DAMAGE ASSESSMENT: No damage on inner surfaces. Cracks on outer surface were associated with large ferrite grain regions which contained stringers of inclusions. Cracking itself appeared to be thermal fatigue related. The inclusions have acted as preferred nucleation sites for the initial ferrite grains hence permitting them to grow to larger size. The cracks preferentially follow these large grains and inclusions.

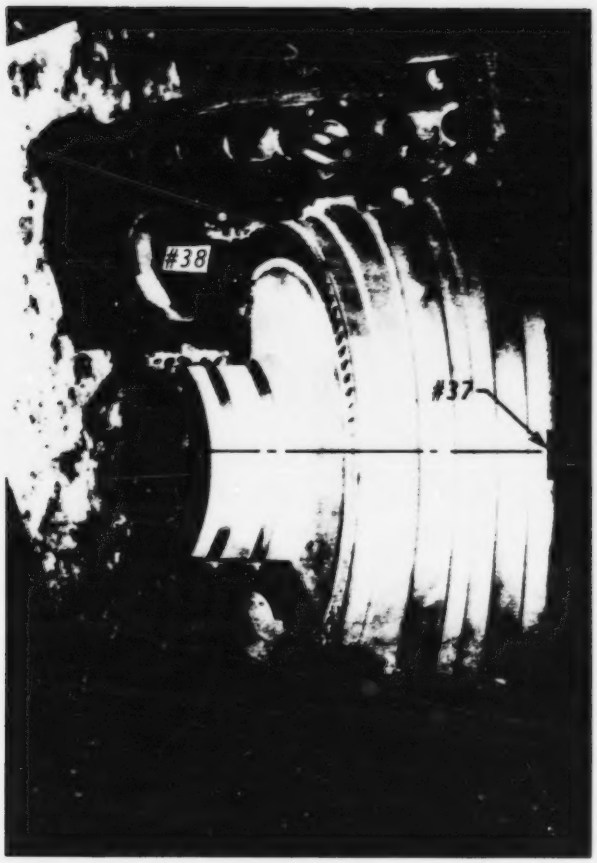


FIGURE B-5
REPLICA LOCATIONS - I.P. INNER CYLINDER, TOP HALF

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: IP Rotor Shaft

MATERIAL: 1Cr 3/4Mo V

AREA DESCRIPTION: 9 areas; #41-45,5 areas on stage 1 disc (hot end)
#46,1 area on stage 8 disc (cold end)
#79,79A,2 areas on gland cracks (hot end)
#80,1 area on shaft cracks between stages 4-5

MICROSTRUCTURE AND HARDNESS

AREA	41	42	43	44	45
STRUCTURE	Bainite	Bainite	Bainite	Bainite	Bainite
HARDNESS (HV)	226	228	227	230	215

DAMAGE ASSESSMENT: No damage in areas 41-45. Comparison to cold end hardnesses indicate only slight thermal softening.

Cracking at hot end (area 79) was largely circumferential and occurred in a region of normal bainitic microstructure. Crack features indicated a fatigue or possibly a thermal fatigue mechanism. No creep damage was detected. The cracks were largely superficial: light grinding removed most of the visual indications; replication after this grindng did detect some small traces of the cracks (less than 0.5 mm).

Cracking in the stage 4-5 area (#80) was more extensive and had the branched and crazed characteristics of quench cracking. The surrounding microstructure consisted of a fine grained bainite-martensite indicating that the steel had been locally overheated at some time. The quench cracks resulted from rapid cooling from this high temperature. This has likely occurred when this rotor was heat straightened in the past.

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: IP Rotor Shaft, continued

MATERIAL: *

AREA DESCRIPTION: *

MICROSTRUCTURE AND HARDNESS

AREA	46	79	79A	80
STRUCTURE	Bainite	Bainite	Bainite	Martensite-Bainite
HARDNESS (HV)	237	ND	ND	ND

DAMAGE ASSESSMENT: *

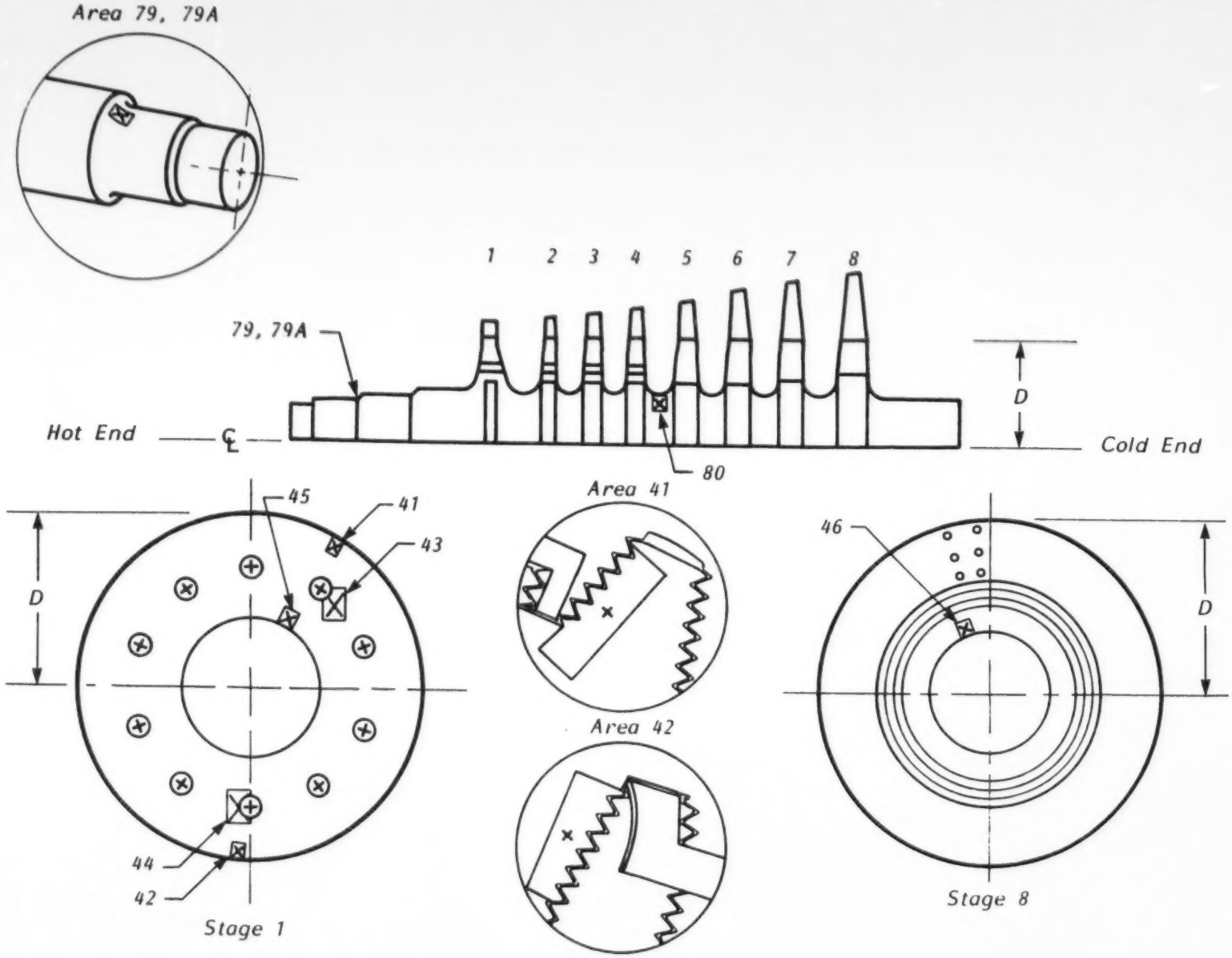


FIGURE B-6
REPLICA LOCATIONS - IP ROTOR SHAFT

176093 RD
87-315

APPENDIX C - BOILER COMPONENTS, HEADERS

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: Primary Superheater Outlet Header

MATERIAL: SA212 Gr B,Carbon steel

AREA DESCRIPTION: 9 areas: nipple welds,#19a,20,21
girth welds,#14,19,16
seam welds,#15,17
nozzle weld,#18

MICROSTRUCTURE AND HARDNESS

AREA		14	15	16	17
STRUCTURE		Ferrite-Pearlite	Ferrite-Pearlite	Ferrite-Pearlite	same
HARDNESS (HV)	BM	128(header)	121	114	123
	HAZ	147	na	128	151
	WM	170	179	168	191
	HAZ	150	146	139	150
	BM	137(head)	124	117	124

DAMAGE ASSESSMENT: No damage was found. The general microstructure is typical for a plain carbon normalized steel consisting of equiaxed ferrite-pearlite mixture but with some degeneration of the pearlite lamellae from the high temperature exposure.

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: Primary Superheater Outlet Header(cont'd)

MATERIAL: *

AREA DESCRIPTION: *

MICROSTRUCTURE AND HARDNESS

AREA	18	19 19A	20	21
STRUCTURE	same	same	same	same
HARDNESS (HV)	BM 131	113	146(feeder)	152(feeder)
	HAZ 151	na	na	na
	WM 184	179	na	na
	HAZ 188	165	162	193
	BM 133	132	131	131

DAMAGE ASSESSMENT: *

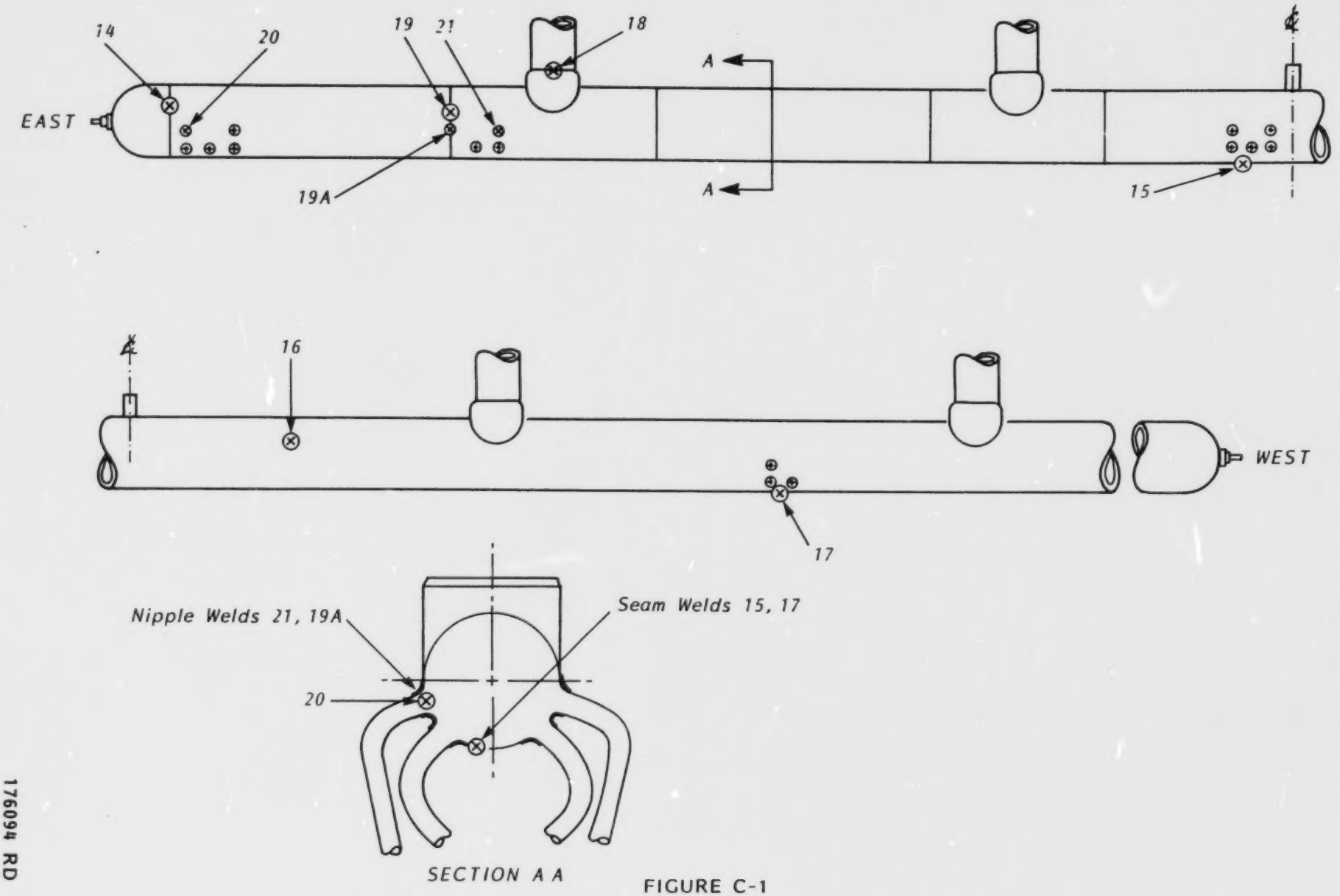


FIGURE C-1

REPLICA LOCATIONS PRIMARY S.H. OUTLET HEADER - FRONT VIEW

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: Reheat Front Horizontal Outlet Header

MATERIAL: 2 1/4Cr 1 Mo SA387 P22

AREA DESCRIPTION: 12 areas: girth welds, #56, 61, 63
seam welds, #65, 67
nozzle welds, #57, 58, 59
nipple welds, #62, 64, 60, 66

MICROSTRUCTURE AND HARDNESS

AREA	56	61	63	65	67
STRUCTURE	ferrite-carbide, bainite in head	ferrite-bainite, carbides	same	same	same
HARDNESS (HV)	BM 120(head)	112	164(nozzle)	104	127
	HAZ 133	129	171	111	138
	WM 182	186	196	120	140
	HAZ 138	139	141	115	143
	BM 131	126	151	110	131

DAMAGE ASSESSMENT: No damage detected. Normal base metal microstructure in the header material was ferrite and upper bainite tempered to produce a ferrite-carbide dispersion.

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: Reheat Front Horizontal Outlet Header(cont'd)

MATERIAL: *

AREA DESCRIPTION: *

MICROSTRUCTURE AND HARDNESS

AREA	57	58	59	62	64	60	66
STRUCTURE	ferrite-carbide	same	same	ferrite-in pipe bainite-in header	"	"	"
HARDNESS (HV)	BM 118(top)	122	115	141(pipe)	98	121	160
	HAZ na	167	150	na	203	na	na
	WM 170	171	150	196	175	158	171
	HAZ 153	164	141	na	138	126	194
	BM 120	115	113	114	104	103	196(girth weld)

DAMAGE ASSESSMENT: *

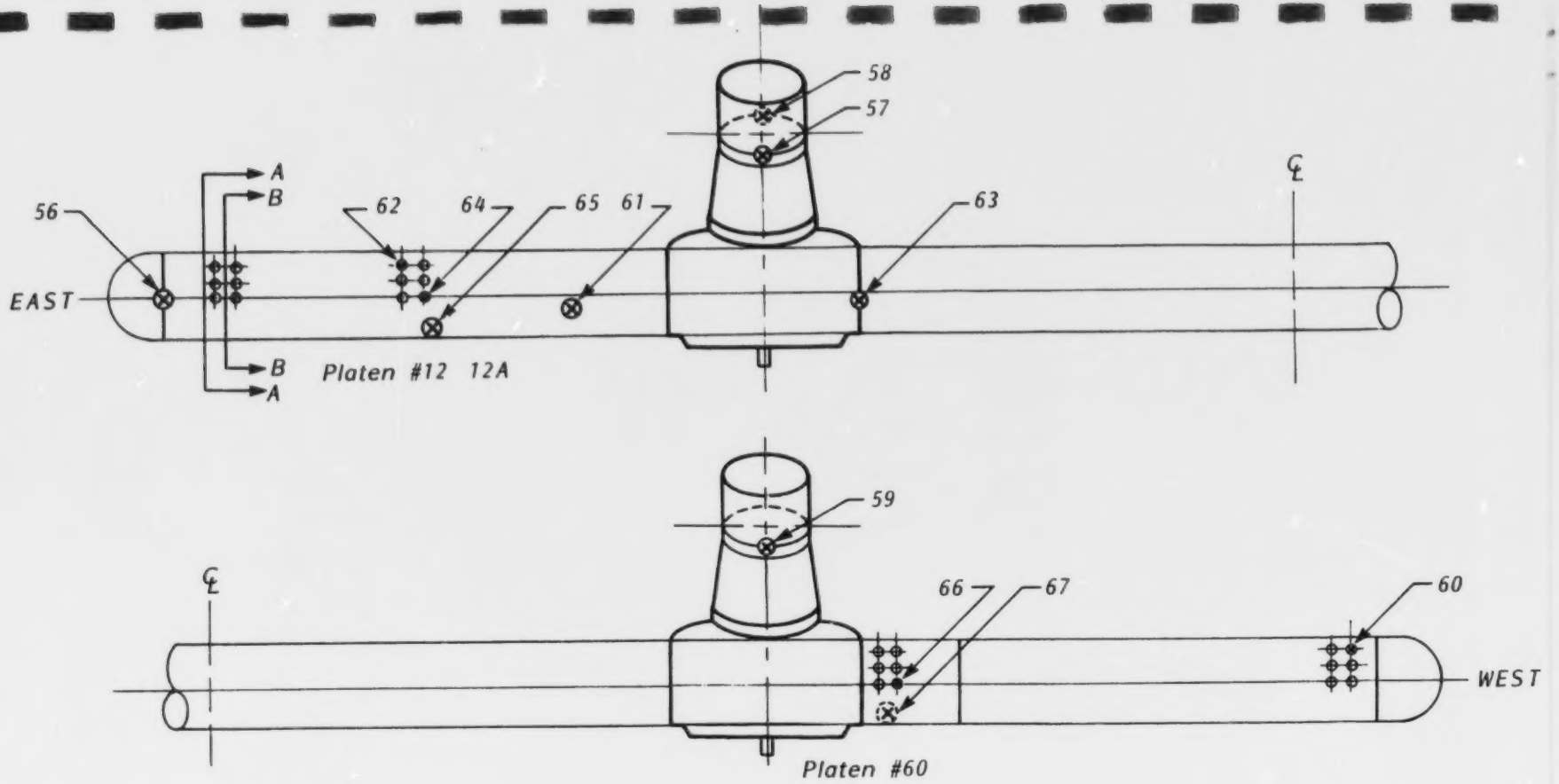


FIGURE C-2

REPLICA LOCATIONS REHEAT OUTLET HEADER - FRONT

176067 RD
87-315

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: Secondary Superheater Outlet Header

MATERIAL: 2 1/4 Cr 1 Mo SA387 P22

AREA DESCRIPTION: 11 areas: girth welds, #68, 71, 72
seam weld, #76
nozzle welds, #69, 73
nipple welds, #70, 74, 75, 77, 78.

MICROSTRUCTURE AND HARDNESS

AREA	68	71	72	76	69	73
STRUCTURE	ferrite-bainite	same	same	same	ferrite bainite	same
HARDNESS (HV)	BM 113(east)	111	na	109(top)	121(pipe)	na
	HAZ 136	128		128	155	
	WM 158	149		136	162	
	HAZ 120	133		113	157	
	BM 108	114		108	110	

DAMAGE ASSESSMENT: No damage detected except for area #70. One large crack was found in this location on the tube side of a nipple weld. The crack was oriented in the circumferential direction, parallel to the weld fusion line and was located close to the HAZ but was mostly in the base metal. Crack features, straight and transgranular, suggest the mechanism as fatigue. No creep damage was found in the adjacent HAZ.

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: Superheater Outlet Header(cont'd)

MATERIAL: *

AREA DESCRIPTION: *

MICROSTRUCTURE AND HARDNESS

AREA	70	74	75	77	78
STRUCTURE	ferrite in pipe ferrite-bainite in header, cracks	same	same	same	same
HARDNESS (HV)	na	na	BM 113(pipe)	111	113
			HAZ 142	na	123
			WM 189	228	129
			HAZ 142	188	125
			BM 105(header)	113	115

DAMAGE ASSESSMENT: *

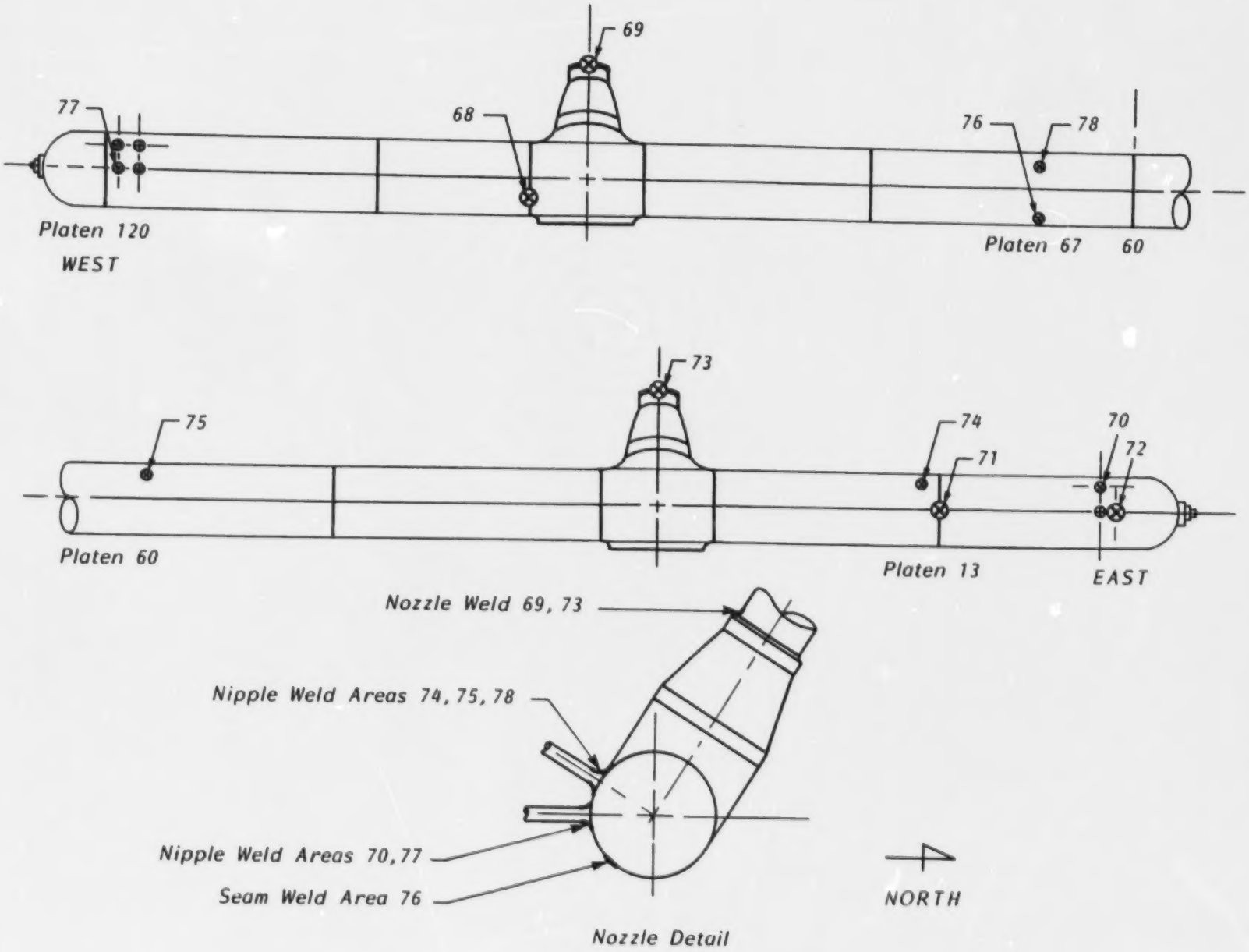


FIGURE C-3

REPLICA LOCATIONS - SECONDARY SUPERHEAT OUTLET HEADER - BACK VIEW

176095 RD
87-315

APPENDIX D - HIGH ENERGY LINES

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: Hot Reheat Steam Piping

MATERIAL: A335 Gr P11 1.1/4 Cr, 1/2 Mo

AREA DESCRIPTION: 7 areas: #84,85,88 welds at bends
#86,87 outside of bends
#94,96 welds at safety valves

MICROSTRUCTURE AND HARDNESS

AREA	84	85	88	86	87	94	96
STRUCTURE	ferrite-carbide	same	same	same	same	same	same
HARDNESS (HV)	BM 137(top)	137	128(north)	122	114	120(pipe)	116
	HAZ 182	163	141			131	135
	WM 181	174	172			168	146
	HAZ 162	148	147			na	na
	BM 132(bot)	122	122			na	na

DAMAGE ASSESSMENT: No damage found.

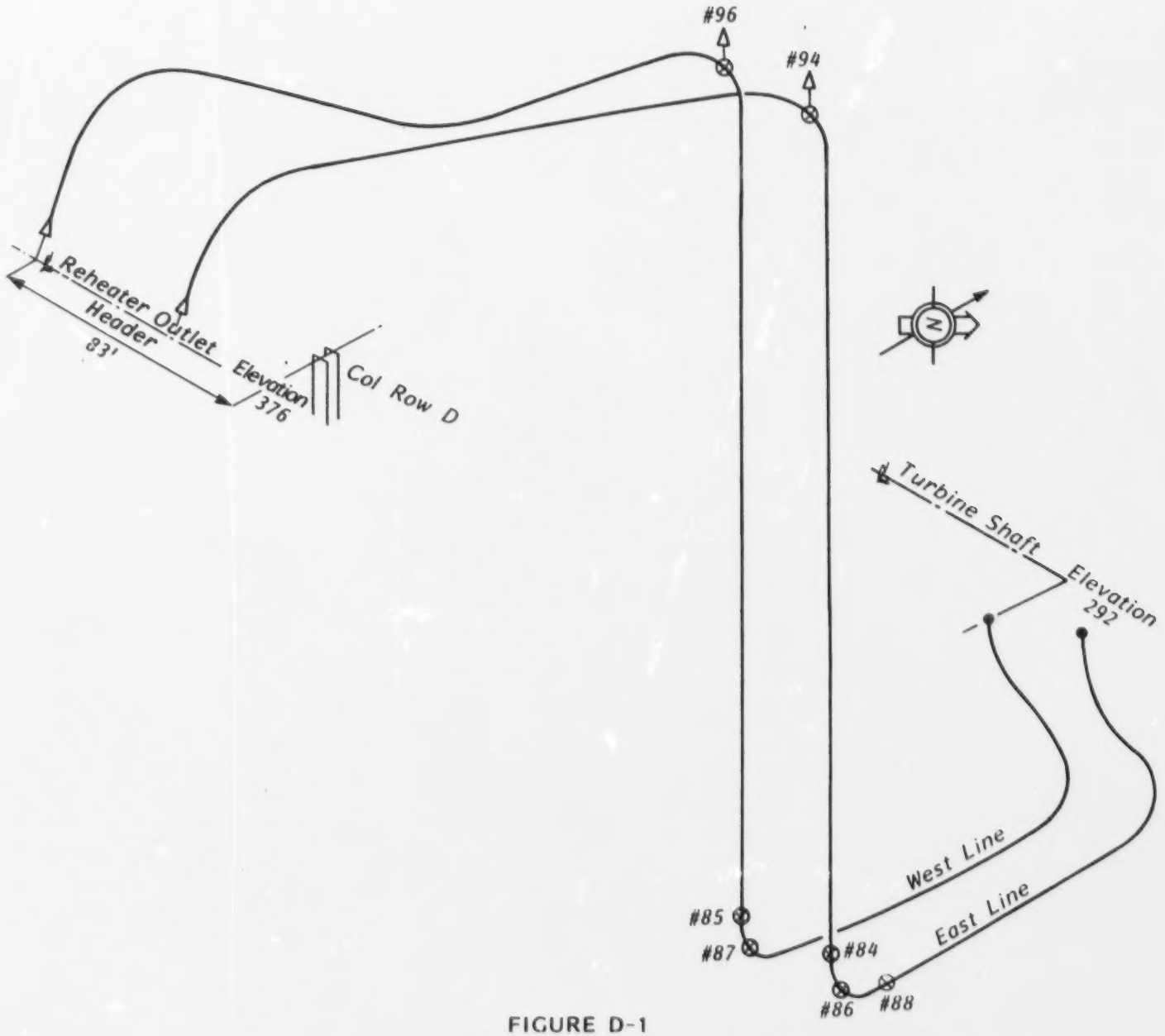


FIGURE D-1
REPLICA LOCATIONS - HOT REHEAT LINES

176096 RD
87-315

EVALUATION FORM FOR REPLICA LIFE ASSESSMENT

COMPONENT: Main Steam Lines

MATERIAL: A335 Gr P11, 1 1/4 Cr 1/2Mo

AREA DESCRIPTION: 7 areas: #89,90 outside of lower bends
#92 horizontal section,upper bend
#91 weld at ESV
#97 weld at bend
#93,95 welds at safety valve

MICROSTRUCTURE AND HARDNESS

AREA	89	90	92	91	97	93	95
STRUCTURE	ferrite-carbide	same	same	same	same	same	same
HARDNESS (HV)	122	122	119	BM 118(south)	122(top)	119(pipe)	124
				HAZ 147	144	132	159
				WM 172	159	168	154
				HAZ na	152	na	na
				BM na	111	na	na

DAMAGE ASSESSMENT: No damage found in these areas, however creep damage was discovered in the terminal welds at the HP steam chests. These are reported in detail in Appendix A, Steam Chest replicas #24,#36,#49.

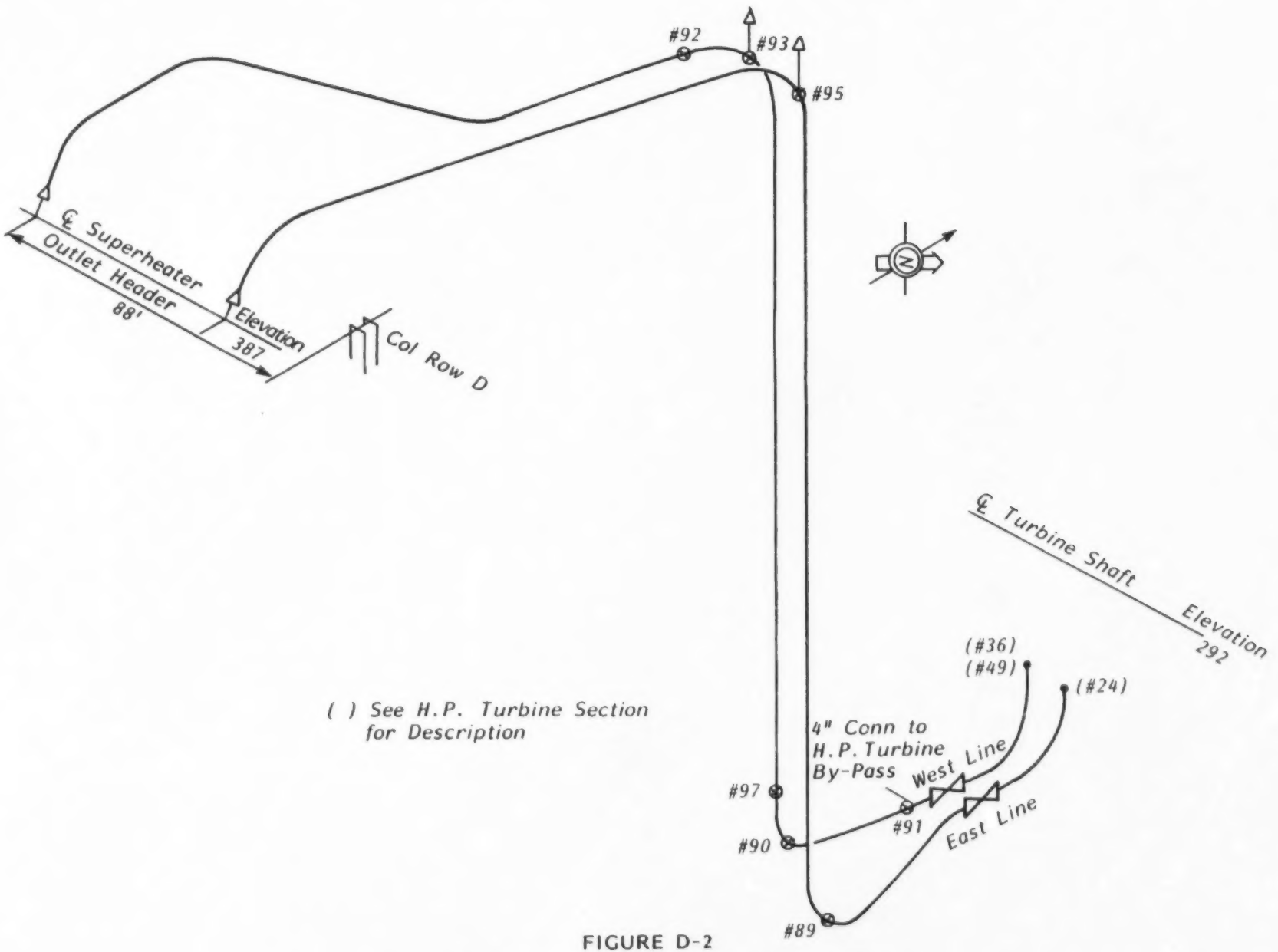


FIGURE D-2

REPLICA LOCATIONS - MAIN STEAM LINES

176097 RD
87-315